The impact of cross-scale interactions on electron-temperature-gradient-driven instabilities in multiscale turbulence

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Electrostatic multiscale turbulence is driven by the ion temperature gradient (ITG) and the electron temperature gradient (ETG) instabilities, at the scales of the ion and electron thermal gyroradii, respectively. Multiscale direct numerical simulations (DNS) (e.g. [1, 2]) reveal interactions between turbulence at the electron-gyroradius and ion-gyroradius scales that contribute significantly to the levels of overall transport. The electron-to-deuterium-ion mass ratio $(m_\mathrm{e}/m_\mathrm{i})^{1/2} \simeq 1/60$ controls the separation between the electron and ion thermal gyroradii, i.e., $\rho_{\mathrm{th,e}}/\rho_{\mathrm{th,i}} \sim (m_\mathrm{e}/m_\mathrm{i})^{1/2}$. As a result of this large scale separation, multiscale DNS are challenging to perform, and reduced models are desirable.

We present a first-principles reduced model [3], valid in the limit of $(m_\mathrm{e}/m_\mathrm{i})^{1/2} \ll 1$, for the impact of ITG-driven turbulence on ETG linear stability [4]. Cross-scale interactions are mediated by parallel-to-the-field shear in the ion-gyroradius scale $\mathbf{E} \times \mathbf{B}$ flow, and by the modification of the background electron density and temperature gradients due to the presence of ion-gyroradius scale fluctuations. We examine the case where both the ITG and ETG instabilities are strongly driven, and find that the ITG-driven turbulence stabilises the ETG instability. We examine the case where the ITG and ETG instabilities are driven near marginal stability, and we find that the impact of cross-scale interaction on the ETG modes can be parameterised by simple modifications of the background drives.

We discuss the possible future applications of this first-principles reduced model for simulating turbulent transport. Given a set of physics parameters, and a corresponding simulation of ion-gyroradius scale turbulence, the reduced model could assess with inexpensive linear simulations whether or not ETG modes are stabilised by the ion-gyroradius scale turbulence, and hence determine whether or not a full multiscale DNS is likely to be necessary.

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References:

[1] S. Maeyama et al. *Nucl. Fusion*, 57:066036, 2017.

[2] N. T. Howard et al. *Nucl. Fusion*, 56:014004, 2016.

[3] M. R. Hardman et al. *Plasma Phys. Control. Fusion*, 61:065025, 2019.

[4] M. R. Hardman et al. *J. Plasma Phys.*, 86:905860601, 2020.